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POSSIBLE ECONOMIC AND TRADE IMPACTS OF THE CURRENT GLOBAL CLIMATE CHANGE DEBATE

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Introduction

The current concerns over global climate change arise from two key observations about the atmosphere: (1) there is a depletion of ozone in the stratosphere, especially over the north and south poles; and (2) there has been a rise in the concentration of carbon dioxide (and some other gases of interest) in the atmosphere since the beginning of the industrial revolution.[1]

Depletion of stratospheric ozone can result in an increase in the amount of short wavelength ultraviolet radiation reaching the surface of the earth. This would not cause a change in climate *per se* but would affect people's behavior in how they apportion their time and activities outdoors. Further, the increase in radiation may affect crops. There are scientific uncertainties here: the "hole" in the antarctic stratospheric ozone has been observed only recently; there is depletion over the arctic, although, a "hole" did not develop; and it is not known if "holes" existed before the introduction of ozone depleting compounds into the atmosphere, knowing that a "hole" is related to complex climatological factors.

Increases in the atmospheric concentration of carbon dioxide (CO_2) and other key gases (some associated with stratospheric ozone depletion) that are opaque to portions of the infrared spectrum result in the "greenhouse effect" or global warming. When short wavelength infrared radiation from the sun warms the earth's surface, and this heat is later radiated from the earth, some gases in the atmosphere are not transparent to the longer wavelength re-radiation, the heat does not escape, and the atmosphere becomes warmer, much as does the interior of a greenhouse.

The greenhouse effect, despite all of the controversy surrounding it, is well based in physics and one of the most well-established theories in atmospheric science. For example, Venus has a dense CO_2 atmosphere and temperatures at its surface of near 1000° C. Nonetheless, there is argument -- or certainly less than unified opinion -- whether the earth is warming. The origins of the 1988 north American drought have been attributed to the greenhouse effect in the popular press, but not in the scientific press, where the origin has been attributed to many other factors.[2] At a 1988 Senate hearing, evidence was presented of trends of increased global temperature and computation of the prediction of a definite greenhouse effect.[3] Months later, the National Oceanic and Atmospheric Administration (NOAA) reported that there was no climate warming in the U.S. judging from 96 years of data.[4] The predictive computations can be questioned given the results of new satellite measurements of the heat radiation of clouds.[5]

The scientific controversy was described at the 1988 Senate hearing by then Energy Undersecretary D. Fitzpatrick as: "These scientific uncertainties must be reduced before we commit the nation's economic future to drastic and potentially misplaced policy responses." At the same hearing, S. Schneider, of the National Center for Atmospheric Research, replied we should "not use platitudes about scientific uncertainty to evade the need to act now."

There is broad consensus that global warming can occur but may not if mitigating steps are taken. The controversy is how much change can be expected, when it will happen, and where its effects will be most evident. Schneider has given an excellent summary of the uncertainties and policy implications of the observations.[6] He approaches the uncertainty issue with the view:

> "Whether some amount of scientific uncertainty is 'enough' to justify action or delay it is not a scientific judgment testable by any standard scientific method. Rather, it is a personal value choice that depends upon whether one fears more investing present resources as a hedge against potential future change or, alternatively, fears rapid future change descending without some attempt to slow it down or work actively to make adaptation to that change easier. That value choice can only be made efficiently by a society in which those involved in the decision-making process are aware of the nature of the scientific evidence."

It is clear at this time that many governments around the world have made the value judgment to proceed as if there will be global climate changes from unnatural (man-made) causes. It is against this background that possible economic and trade effects are discussed. To do so, it is not necessary to enter the debate of the nature, magnitude and timing of global climate change. It is only necessary to consider currently proposed responses. This is done in a global context, not focusing on any one country. However, the situation in the U.S. is stressed because more data are readily available.

Some Economic Effects of Global Warming

The mathematical models of global climate change predict average likely global temperature change and, to an extent, new global temperature patterns. From this, specific effects on natural ecosystems, water supplies, agriculture, sea levels, are inferred. Models are not capable of reproducing regional temperatures or precipitation. Nonetheless, there is qualitative agreement among prognosticators that sea levels will rise (although the evidence available is that the natural rise in levels has not accelerated[7]), wetlands will flood, salt water will infuse fresh water supplies, and there will be changes in the distribution of tree and crop species and agricultural productivity. Some writers have succumbed to the temptation to "predict" the quantitative extent of these changes, but such predictions are not much more than speculation. The "predicted" time scale for these changes ranges from decades to centuries.

A significant rise in sea levels will flood now habitable land in some countries, such as in Bangladesh, an already crowded country. Developed countries may be able to protect their cities, at least for a some years, by building levees and dikes at a considerable cost to avoid major displacements of people and their economic bases.

These same actions will affect wetlands and it may not be possible protect both coastal and wetland areas. Flooding will intrude into water supplies, such as in coastal cities (*e.g.,* Miami and New Orleans). In the Netherlands, it is expected that if the sea level rises a meter or more, large areas of the country will have to be flooded with fresh water to prevent saltwater intrusion.[7]

Changes in temperature patterns will affect natural ecosystems by altering the distributions of species. and affecting forestry and silvaculture. Under various scenarios, commonly harvested species will move north and try to grow in different soil types. Ranges of particular species are likely to change because trees in the southern part of the present range may die off much more quickly than they can propagate further north. Managed forests can survive if new species and strains can be developed in advance of any climate change.

Similarly, crop lands will change. In present farm areas, there will be greater reliance on irrigation. The stress will depend on changes in precipitation patterns, which is now difficult (at best) to predict. Grain production will move north and productivity may fall because of differing soil types. Global warming could expand the northern range of livestock diseases and pests.

Global warming will affect snowfall patterns, hence melt, and affect water supplies. Most of California's water supplies are from snow melt and if snow is reduced to rain, or melts quickly during the winter, water supplies in the summer will be less than now.

Likely Actions to Cope with Global Warming

Society does not have the resources to hedge against all possible future outcomes of global warming and other climate changes. Therefore, Schneider suggests a "tie-in" strategy of pursuing those actions that provide widely agreed societal benefits even if the predicted change does not materialize.[6] He suggests increased energy efficiency, reductions in emissions from many fossil fuels (especially from coal), development of alternative technologies such as in the development and testing of new crop strains, and trading agreements with nations for food or other climatically dependent strategic commodities. The consensus for "tie-in" strategies appears to favor some combination of emission reductions to slow the eventual warming and adaptation to an amount of inevitable warming.[7]

Schneider also raises the question whether it is more appropriate to subsidize poverty, for example, through artificially lower prices of energy which discourage its efficient use, or is it better to diminish poverty by direct economic aid. He suggests that it may be necessary to charge user fees on industrial activities in proportion to the amount of pollution each generates, a strategy which will differentially impact less developed nations, coal miners, or the poor, which raises questions of equity.

The actions likely to be taken by governments are: (1) reduce the emission of CO_2 by reducing the use or the mix of fossil fuels; (2) reduce the emissions of potential pollutants; (3) improve energy efficiency; (4) ban or restrict the manufacture of certain chemicals; and (5) seek to affect natural emissions of key chemical compounds. Each of these is discussed below in terms of its potential effects on economy and trade.

Trade effects are considered in terms of comparative advantage assuming a level playing field in the trade arena, recognizing this does not always happen. It is also assumed that all trading countries will adhere to future international compacts on global warming. Needless to say, large importing and/or exporting countries

can distort any of the trade effects of global climate change by choosing to ignore, or seeking exceptions from, international agreements.

Reducing the Use of Fossil Fuels

Emissions of CO_2 (per unit of power produced) can be reduced by using a more thermally efficient fossil fuel-boiler combination, hence changing the mix among currently used fuels. The usual suggestion is to replace coal with natural gas. If this were done on a large scale, it would require the exploration, development and production of new gas fields. There would be a consequent reduction in production and export of coal. Both actions would affect the internal economies of coal and gas producing nations and affect the balance of trade among current coal trading partners. The cost of conversion of a coal-fired boiler to gas is relatively low. However, investments will be required for adequate gas delivery and distribution systems.

Displacement of coal by some other fuel will cause worker displacements in coal producing countries. Historically, coal miners have not found other employment easily. Hence, displacement of coal will likely cause large economic and social displacements which, in turn, will cause coal producing countries to seek some sort of aid for the workers. This economic disruption will be asymmetric, likely causing those affected to take action to defend their national economies. The wins and losses in the world economy are likely to be large.

Changes in fuel mix will not be well received by developing countries with large indigenous coal reserves who may not have domestic gas reserves or the capital to explore for and develop such supplies. These countries will be among the big losers and this alone could cause delays in reducing the amount of coal burned. At the same time, there must be analysis and consideration of what effect coal displacement will have on total worldwide CO_2 reduction. It is possible that the amount of CO_2 reduction from coal displacement will not be worth the economic result.

Fossil-fueled plants can be replaced with nuclear plants. If so, some risks will remain and the costs of development and gaining acceptance will be high. This option, too, will favor the wealthier nations or those who have already made a large investment in nuclear power, such as France, Japan, and to an extent the U.S., the U.K., and others.

The *per capita* generation of CO_2 in developed countries is, of course, much higher than in developing countries. One compilation ranks, in descending order, East Germany, U.S., Czechoslovakia, Canada, Australia, U.S.S.R. etc. down to India and Mexico.[7] However, if China meets its goal of raising its *per capita* gross national product to only 15% of the U.S. figure, the increase in CO_2 emissions in China would about equal emissions from all the coal consumed in the U.S. Similarly, if India maintains its current *per capita* emissions, its population growth will cause a similar increase in CO_2 emissions by the middle of the next century.[7] Clearly, even if very drastic steps to reduce CO_2 emissions in the U.S. were undertaken, it would not reduce worldwide emissions. This begs the question of developed countries giving some developing countries a "gift" of nuclear plants.

Alternative ways of reducing emissions are to use less energy, use it more efficiently, and to generate it from other than combustion. Non-use is not an option for a world economy based on energy intensity. Developing nations want to increase their energy use so as to improve the value added aspects of their economies and provide the basic necessities and amenities for their people.

Alternatives to fossil fuels (wind power, photovoltaic, solar collectors, etc.) are not being used because they currently cost more than fossil fuels. Hydroelectric power is in widespread use but there are not many more places for new major installations (and there are serious environmental and cost concerns). Aside from major new hydroelectric capacity, alternative generating technologies may benefit developing nations. These technologies are generally applied at small scales so that capital requirements are low. However, net cost per energy unit produced is likely to be uncompetitively high which would affect their international trade.

A major use of oil is for liquid transportation fuel and there are few viable alternatives on the horizon. If this use were cut back, say by fiat, reducing transportation would slow the economy of developed nations and hinder economic growth among developing nations. Not to be overlooked, large reductions in use of oil would seriously affect the economies of oil producing nations, many of which rely significantly on the revenues from oil exports to pay for their imports. Developed countries will have to increase their efficiency of transportation fuel use. In general, this means a switch to smaller and more efficient automobiles which has the related effect on economies of reduced manufacturing. Whereas workers may not be displaced, certainly the value added from the manufacturing is lowered.

Reduce Emissions

If there is to be international agreement to further reduce greenhouse gas emissions, this will give a competitive advantage to nations that have already invested in pollution control technology and will require considerable capital investment by countries that can ill afford it. If the effects of such investment around the world parallel those in the U.S., there will be increases in inflation and a lowering of GNP.[8] It has also been observed that increased spending on pollution control favors large plants over small[9] and results in a decrease in productivity.[10]

The principal contributor to the predicted global climate change is CO_2. A major source of this gas is from the combustion of fossil fuels. There does not seem to be any reasonable technological nor economic way to remove CO_2 emissions from combustion products so this form of emission control is not an option.

Another principal contributor to the predicted global climate change is methane. Some industrial releases are easy to control; other releases, such as from natural biodegradation (including from landfills) are more difficult. At the same time, there has to be an inventory of sources in order to learn if they warrant control.

Improve Energy Efficiency

One of the principal ways to slow down the rate at which CO_2 is generated is to invest in more efficient use and production of energy, including replacement of older power generating units. Such actions will favor the wealthier nations who can afford the investment. Devices and technology for improving efficiency are bases for new businesses. However, the inventions and developments will likely be in the wealthier nations. There should be considerable trade in means to improve efficiency and the trade victory will no doubt fall to those swift in acquiring the devices and means. It can be generally accepted that increased energy efficiency improves competitiveness.

Ban or Restrict Production

If the world community decides to ban the production of any chemical contributing to global climate change, such as certain chloroflurocarbons (CFC's), the ban must be equitable in two ways. First, any ban must be complete, with no long extensions that may favor one country over another. Second, bans should be implemented only if suitable substitutes are available. Bans should not remove the means (CFC's) of providing economical and safe refrigeration and air conditioning from nations' economies.

Restrictions are even more difficult. There already has been a restriction on the use of CFC's for aerosol products in the United States. This resulted in U.S. industry surrendering some of the market to other countries. If future restrictions of CFC's do not take this into account (and it appears the Montreal Protocol hasn't), then U. S. industry will make another sacrifice.

The ultimate restriction would be to place a cap on global productive capacity and to allocate portions among nations. The folly of such a plan should be self-evident given the inability of even individual nations to centrally plan their economies. There have been suggestions to allocate production within a country by imposing production charges (taxes) on certain fuels or products, with the related effect of having the magnitude of these charges distribute use of the products.[6] Such schemes may be appealing in theory, especially to those who advocate "market solutions" to all problems. However, these schemes presume a value can be assigned to the allocations. Even if a bid process were used to assign the values, the scheme clearly favors the most wealthy and would result in predation among nations and companies.

Affecting Natural Emissions

There are large natural sources of CO_2 and methane emissions, such as from the decomposition of organic matter, from volcanoes (which is the largest source of carbon monoxide), from ruminating animals (methane and carbon monoxide) and from mammalian exhale. Thus, CO_2 can be limited by control of the populations of animals and people.

There are serious concerns about methane in the atmosphere. There has been a linear increase in atmospheric methane in the past decade, current levels are more than twice as high as before the industrial revolution, and methane is one of the fastest growing greenhouse gases.[7] More than half of the methane released to the atmosphere comes from decay of organic material (including peat bogs, rice paddies and wetlands) and from ruminating animals. It is also released from coal mines, leaks from gas production and transportation, and landfills.

There are obvious economic consequences from the control of the population of people, both good and bad, depending on which country is being discussed. There are also obvious economic consequences of controlling the population of domestic animals. Certainly the world could move toward consumption of more vegetable protein, instead of animal protein, reversing the trend of centuries. If people would accept such change, there might be economic and trade benefits to grain producing nations and disbenefits to animal producing nations. However, even the grain producing nations with the largest comparative advantage would suffer because large quantities of grain are used for animal feed. Any major decrease in animal population would hurt farmers and ranchers. Historically, countries are prone to protect their farmers from international trade disadvantages so shifts in farm production is likely to result in protectionism.

The largest way to affect natural emissions may be to alter the CO_2 cycle by photosynthesis. Green plants absorb CO_2, metabolize it for growth, and emit oxygen. Indeed, reduction of tropical forests is often blamed for the increase in atmospheric CO_2. However, this blame is usually without cogent scientific analysis. Some questions remain concerning how much new forest (really green plant) growth is needed to make a difference and where should this growth take place. For example, can deforestation in Africa or South America be compensated by new plantings in North America?

Aestheticians will prefer planting of trees over other types of green plants. However, young plants are more effective in consuming CO_2 than mature trees. Short rotation forestry will have to be instituted in developing countries to provide both reforestation and firewood. However, these countries are likely to need aid in establishing and managing such crops. A balance must be found among the competing interests of growing plants and wood, the CO_2 that will result from the inefficient burning of the firewood, and providing fuel for people. The developing countries will have to find the economic means of establishing short rotation tree crops and equitable distribution of the fuel. Present wood-cutting and scavenging practices would have to be replaced with an economic allocation among the poor which probably means a subsidy scheme. It has been reported that only a small proportion of the fuel wood used by the rural poor comes from forests. Villagers rarely chop down trees but collect dead branches or cut them from trees. At the same time, 70% of the people in developing countries use wood for fuel.[11]

If deforestation is a large cause of climate change, and must be stopped, then those doing the deforestation must be offered an alternative. Forest products also provide foreign exchange. Poverty that requires cutting of fuel wood must be reversed by sustainable economic development and economic alternative silvaculture practices must be instituted by producing nations. To do otherwise has the large negative effect of maintaining poverty and reducing trade in needed hardwoods.

Predation Through Environmental Controls

An interesting analysis of environmental regulation in the U. S. concluded that certain industry groups and labor unions benefit from this regulation because of increases in profits and wages.[12] The thesis can be extended, at least qualitatively, to the effects on economics and trade that may result from worldwide imposition of new environmental controls.

Pronounced heterogeneity among firms and countries gives rise to competitive advantages due to asymmetric distributions of control and compliance. For example, if the regulatory cost burden falls heavily on one group of firms or countries, and lightly on another, then the indirect effect of the regulations is a cost advantage to the second group. Competitor damage and predator benefits accrue.

To the extent that there are economies of scale in compliance, smaller and/or less efficient enterprises or countries that have not yet invested in environmental regulation suffer a large unit-cost effect and exit the industry. Environmental regulations may affect one portion of the world more than others, similarly producing asymmetries that result in cost advantages.

In the United States, industries faced with stiff import competition are heavily damaged by regulation[9] and it is easy to see how any uneven installation or application of environmental restrictions will shift predatory benefits among nations.

A Policy Course

There is a spectrum of suggested policy actions. At one end, some favor immediate preventive actions, pointing to the uncertainties in prediction and effects. They argue that the effects could be far more severe or rapid than models predict. At the other end, others argue that reducing or curtailing emissions is so difficult and involves so many activities that are basic to human life, that global warming will be nearly impossible to prevent or even slow. They advocate adaptation, which obviously will be very expensive. Somewhere in the spectrum is a school of thought that there are so many uncertainties of timing and effects that society should not invest time or money until the problem is better understood. The more middle ground of some combination of emission reductions and adaptation is winning favor because, in part, of the greenhouse gases already in the environment. Economic and trade effects should be measured today against this middle view.

Controlling emissions of "greenhouse gases" (notably, but not only, CO_2) presents choices similar to many energy and environmental problems. There is a mix of social, strategic, economic and environmental issues that must be balanced. In all cases, not to do so will distort national economies and trade, as shown by the discussion above. As a basic premise, it would be unwise to establish energy and environmental policies that are driven solely by concerns over climate change.

There must be a better scientific understanding of the relationship between the magnitude and potential for these changes and the processes affecting the global carbon cycle. Valid and effective policies, based on their merit and not on speculation, can be established. At the same time, it would be a mistake to ignore the forecasts or to abandon established policies in favor of those that may have profound and unknown (and possibly negative) economic, social and climatological effects.

Noteworthy, the U.S. has sustained a long period of economic growth with diminishing emissions of CO_2. Fig. 1 in the Appendix shows graphs for the changes in CO_2 emissions and in GNP over the period from 1973 to 1988. Emissions peaked in about 1979, dipped and then rose again in 1988. However, at the same time, GNP increased steadily. More informative, Fig. 2 in the Appendix graphs the ratio of emissions to GNP over the period from 1973 to 1988. Over the entire period, the ratio decreases, showing increased economic output with decreased emissions. This experience is a lesson for the rest of the world, showing that sustainable economic development need not be accompanied by greatly increased emissions. The challenge is to identify what was done correctly and implement the policies elsewhere.

Sustainable economic growth is an imperative, especially among developing nations.[13] Only wealthy nations can afford strict environmental controls. U. S. experience is that the rate of CO_2 emissions *per unit of economic output* has declined. The developed nations have an obligation to continue this kind of growth and to teach the developing nations how to achieve similar results.

International cooperation is essential to mitigate potential man-made climate change. This cooperation must include the following steps.

- Educate people around the world about global climate change and the choices that may be necessary to avoid it.

- Support international cooperative research to advance everyone's ability to predict and act.

- Developed nations must take a pro-active role in implementing changes that will mitigate unnaturally caused climate changes. These actions must make economic, social and environmental sense on their own merits.

- Developed nations must assist developing nations in joining the global efforts while maintaining their economic growth. Some ways this may be accomplished are R&D growth, trade incentives, land and forest management, and adoption of new agricultural practices.

- Implement new global regulatory policies in an even-handed way so as to avoid predation.

The World Commission on Environment and Development suggested a similar policy course[14]: improved monitoring and assessment of the evolving global climate change phenomena; increased research to improve knowledge about the origins, mechanisms and effects; the development of internationally agreed policies for the reduction of the causative gases; and adoption of strategies needed to minimize damage and cope. The Commission concluded: "It is clear that a low energy path is the best way towards a sustainable future. But given efficient and productive uses of primary energy, including sustainable forms of renewable energy, this need not mean a shortage of essential energy services."[15] Although the Commission did not address economic and trade changes, it did add, "This requires profound structural changes in socioeconomic and institutional arrangements and is an important challenge to global society."

Discussion

The various proposed worldwide strategies to respond to potential global climate change have mostly negative effects on trade and the economies of developed and developing nations. At the same time, the proposed policy course must include a balance among the mix of social, strategic, economic and environmental issues.

There are going to be extremes of view. One will be that all decision making ultimately is reduced to a question of economics; another is that economic considerations must never play a part in issues affecting public health and the environment. There must be a middle ground of analysis and prudence or people all over the world will suffer.

Strict prevention policies will always be controversial because they involve, in some cases, substantial immediate investments against the possibility of future environmental changes. These can not be predicted with precision or assurance, leaving a question whether it is better to act now against a potential threat or wait until the threat is real. The economic answer to this question depends on the discount rate used to value potential future losses. For example, it has been estimated that damage from a sea level rise of 8 m could cost about $1 trillion (1971 dollars) some 150 years in the future. At a discount rate of 7% per year, this hypothesized loss is worth only some $33 million today.[16] The 8 m rise may not be probable[6], but the example is instructive. Of course, such an approach of discounting the far distant future may not be rational.

Two important caveats: First, no one country can be singled out for making proportionally more changes in their economy than others in order to mitigate global climate change. It is popular to ask the U.S. to

make the greatest sacrifices, even though it has been calculated that the U.S. contributes some 5% of CO_2 emissions and this fraction could drop significantly if the U.S. reduces growth while other nations with large populations try to increase their GNP.[17] Another computation is that fossil-fuel plants in the U.S. are responsible for about 28% of the country's domestically generated CO_2 emissions, and that these emissions from all U.S. sources account for about 26% of worldwide CO_2 emissions. This means that U.S. power plants contribute just over 7% to worldwide CO_2 emissions, and half that when other greenhouse gases are taken into account.[18] Thus, the focus has to be on the economies of developing nations and a solution might be to construct nuclear power plants in these countries.

The second caveat is that before there are new global agreements to make large changes in national economies and world trade, there have to be sufficient analyses to provide a basis for choosing strategies. If, for example, photosynthesis can absorb enough excess CO_2 to avoid perturbating the economy, then there should be efforts to grow more green plants, wherever in the world they will have the greatest effect.

In this environmental issue, perhaps more than in any other, Pogo described it best: "We have met the enemy, and it is us."

APPENDIX

Computation of U.S. Emissions and Comparison to GNP

Emissions of CO_2 in the U.S. were computed from the energy use reported by the Energy Information Agency, U.S. Department of Energy, 1973-1988, for coal, oil and natural gas. These are listed in Table 1 in quadrillion (10^{15}) BTU (British Thermal Units). (Figures are taken from the October 1988 Monthly Energy Review (released January 1989). Figures for 1988 are estimated based on 10 month totals. Energy use was converted to CO_2 emissions in the following way.

A "typical coal" of 12,550 BTU/lb calorific value with a 70.4% carbon content was assumed. This is a reasonable choice based on listings of typical coals, such as in the *Handbook of Chemistry and Physics*.

A "typical oil" of 19,250 BTU/lb calorific value with a 84.8% carbon content was assumed. This, too, is a reasonable choice based on similar listings of typical U.S. crude oils.

A "typical gas" need not be assumed. Values used for methane were 1000 BTU/ft^3 with a density of 0.0423 lb/ft^3.

The computation of the amount of CO_2 produced is then:

$$[CO_2] = (\text{energy consumption/calorific value}) \times \text{carbon content} \times (44/12)$$

The factor (44/12) is the ratio of molecular weights of CO_2 to carbon. (The computation for natural gas includes multiplying by the density to convert ft^3 to pounds.) The results are listed in Table 1 in units of billions

of tons. Note that many other such listings are in units of tons of carbon emitted, not CO_2. The CO_2 result can be divided by (44/12) to convert to tons of carbon.

Values for the U.S. Gross National Product (GNP) are from the *Statistical Abstract of the United States, 1988*. The value for 1988 was supplied by the U.S. Department of Commerce. Values for GNP are in constant 1982 dollars. These, too, are listed in Table 1.

Table 1 also lists the ratio of total CO_2 emissions to GNP, multiplied by 1000 so as to avoid listing very small fractions. (More significant figures are indicated for the listing of emissions than just justified by the data.)

Figure 1 graphs both the changes in CO_2 emissions (the bars) and changes in GNP (symbols and lines) over the time period from 1973 to 1988. Emissions grew until 1979, dipped through 1983, then leveled off until 1987 when they grew again, but to lower values than 1979. For almost every year during this time period, GNP increased year to year.

Perhaps more instructive is Figure 2, showing the change in the ratio of emissions/GNP over the same time period. There has been a steady decrease in this ratio since 1976, showing a decrease in emissions with an increase in economic output. The ratio for 1988 is slightly higher than for 1987; it is not known if this one point signals a trend.

It is significant that U.S. population in 1970 was 203,302,000 which grew to 226,546,000 in 1980. It was estimated to be 241,078,000 in 1986 (*Statistical Abstract of the United States, 1988*). There has to be a relationship between population and CO_2 emissions, but this was not explored.

Notes and References

(1) Some of the early measurements of the CO_2 content of air can be questioned because of subsequent improvements in analytical methodology. Early colorimetric titration techniques are known to be faulty. However, accounting for these errors may only shift the trends in concentration, not make them invalid.

(2) K. E. Trenberth, G. W. Branstator, P. A. Arkin. 1988. Origins of the 1988 North American Drought. *Science*. 242: 1640.

(3) J. Hansen. 1988. Testimony to Senate Energy Committee, 23 June. Hansen stated that the greenhouse effect was "99% likely to be associated with the recent temperature trends."

(4) P. J. Hilts. 1989. No Global Warming Seen in 96 Years of U. S. Data. *Washington Post*. January 27.

(5) V. Ramanthan, *et al.* 1989. Cloud-Radiative Forcing and Climate: Results from the Earth Radiation Budget Experiment. *Science*. 242: 57.

(6) S. H. Schneider. 1989. The Greenhouse Effect: Science and Policy. *Science*. 243: 771.

(7) B. Hilleman. 1989. *Chemical & Engineering News*. March 13.

(8) P. R. Portney. 1981. The Macroeconomic Impacts of Federal Environmental Regulation. *Environmental Regulation and the U.S. Economy.* H. M. Peskin, P. R. Portney, A. V. Kneese, editors. Resources for the Future. Johns Hopkins University Press. Baltimore.

(9)B. P. Pashigian. 1984. The Effect of Environmental Regulation on Optimal Plant Size and Factor Shares. *J. Law & Economics.* 27: 1.

(10) W. Gray. 1987. The Cost of Regulation: OSHA, EPA and the Productivity Slowdown. *Amer. Economic Rev.* 77: 998.

(11) World Commission on Environment and Development. 1987. *Our Common Future.* Oxford University Press. New York. pages 189, 190.

(12) A. P. Bartel and L. G. Thomas. 1987. Predation through Regulations: The Wage and Profit Effects on the Occupational Safety and Health Administration and the Environmental Protection Agency. *J. Law & Economics.* 30: 239.

(13) This has been called the "growth imperative" by the United Nations Environment Programme (UNEP). See: United Nations Environment Programme. 1981. *The Environment in 1982. Retrospect and Prospect.* Paper UNEP/GC(SSC)/2. Nairobi.

(14) Reference 11, page 176.

(15) Reference 11. Page 201.

(16) S. H. Schneider and R. S. Chen. 1980. Carbon Dioxide Warming and Coastline Flooding: Physical Factors and Climatic Impact. *Annual Review Energy.* 5: 107-40.

(17) S. H. Schneider, reference 6, footnote 73.

(18) H. H. Landsberg. Coal Revisited. 1989. *Resources.* No. 94. p. 10. Resources for the Future. Washington.

Table 1: Computation of Carbon Dioxide Emissions, 1973–1988

year	Heat Output coal	Emissions coal	Heat Output nat. gas	Emissions nat. gas	Heat Output oil	Emissions oil	Total Emissions	GNP 1982 $ trillion	Ratio (Ttl.Emissions/ GNP) x 1000
1973	13.0	1.337	22.5	1.309	34.8	2.811	5.456	2.74	1.988
1974	12.7	1.306	21.7	1.262	33.5	2.706	5.274	2.73	1.932
1975	12.7	1.306	20.0	1.163	32.7	2.641	5.110	2.70	1.896
1976	13.6	1.399	20.4	1.187	35.2	2.843	5.428	2.83	1.920
1977	13.9	1.430	19.9	1.157	37.1	2.996	5.583	2.96	1.887
1978	13.8	1.419	20.0	1.163	38.0	3.069	5.651	3.12	1.814
1979	15.0	1.543	20.7	1.204	37.1	2.996	5.743	3.19	1.799
1980	15.4	1.584	20.4	1.187	34.2	2.762	5.532	3.19	1.736
1981	15.9	1.635	19.9	1.157	31.9	2.576	5.369	3.25	1.652
1982	15.3	1.573	18.5	1.076	30.2	2.439	5.088	3.17	1.607
1983	15.9	1.635	17.4	1.012	30.1	2.431	5.078	3.28	1.549
1984	17.1	1.759	18.5	1.076	31.1	2.512	5.346	3.50	1.527
1985	17.5	1.800	17.8	1.035	30.9	2.496	5.331	3.62	1.473
1986	17.3	1.779	16.7	0.971	32.2	2.601	5.351	3.72	1.438
1987	18.0	1.851	17.2	1.000	32.6	2.633	5.484	3.85	1.426
1988	19.0	1.954	18.3	1.064	33.6	2.714	5.732	4.00	1.435

Notes: Heat output units are in quadrillion BTU.
Emissions units are billions of tons of carbon dioxide.
GNP units are constant 1982 dollars (trillion).

Fig. 1: Total Carbon Dioxide Emissions and GNP Variations 1973 - 1988
Bars = Carbon Dioxide Emissions; Line = GNP

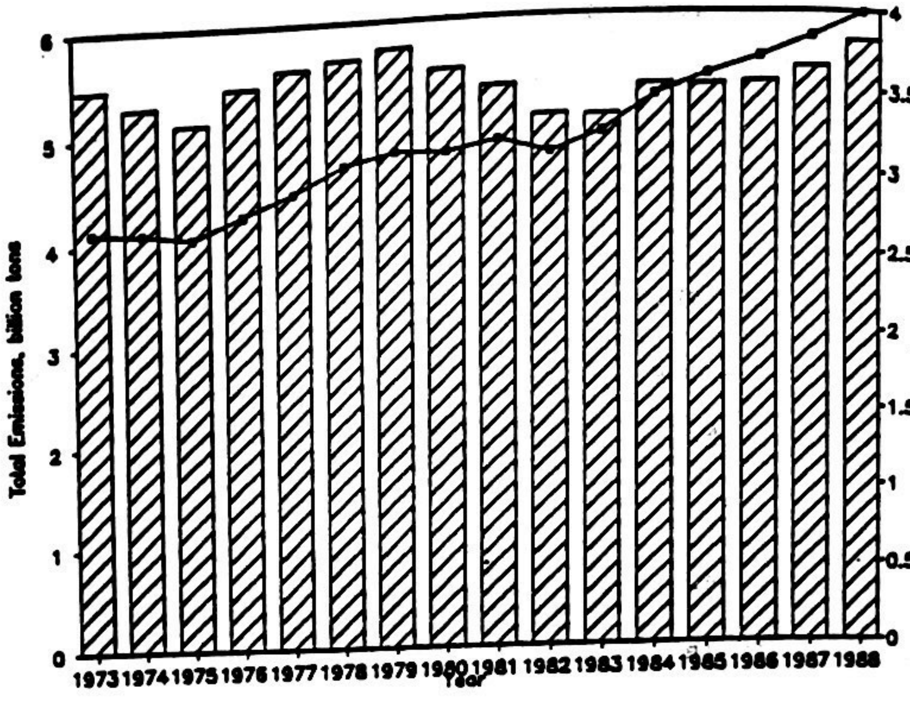

Fig. 2: Ratio (Carbon Dioxide Emissions/GNP) x 1000 from 1973 to 1988